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Computer-aided Coordination of power system Protection

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***Abstract*—In electrical power networks faults can occur for various reasons. The task of the protection devices in electrical power systems (EPSs) is to detect these faults and to eliminate the faulty parts of an EPS. In order to minimise the fault's consequences, different protection devices have to be coordinated. In this article a computer-aided approach is described that should help project-planning engineers with this task and reduce the very time-consuming procedure of protection-strategy development and documentation preparation to a minimum. The main goal of the proposed concept is to make the tool as user-friendly as possible. The user communicates with a program system and device databases via a graphical user interface (GUI), which enables the visualisation of a network. The clear graphical representation of the problem reduces the possibility of human errors. In this paper the concept of the tool for overcurrent, overload and distance-protection coordination, its main features, and a typical example are presented.**

***Index Terms*—power system protection, power engineering software, protection devices**

I. Introduction

COORDINATION of protection can be defined as the systematic application of multiple protection devices in electrical power systems (EPSs). The objective of this coordination is to disconnect the faulty or overloaded parts of an EPS in order to minimise any equipment damage, process-outage costs and risks to personnel. Depending on the voltage level, the type of network, and the importance of the operation in various parts of an EPS or the characteristics of the load, various protection devices are used in order to realize the desired protection philosophy.

The coordination of protection devices in large networks is a time-consuming operation that includes: minimum and maximum fault-current calculations for various network configurations; working out a general proposal for the selective grading of relays; setting the parameters of protection devices; drawing and checking the grading diagrams based on relay-tripping characteristics; and preparation of the relay-setting documentation. Without a computer this might eventually be possible, but only for time-independent overcurrent devices. When applying time-dependent characteristics, without a computer this is just not possible in a reasonable time. As a result, programs have been developed to help project-planning engineers solve these problems [1,2]. The computers help in calculating the fault currents; setting the pick-up and release criteria of the protection equipment; and creating grading paths and curve charts. The results are documented in the form of grading paths and diagrams as well as protection device setting tables.

As the protection coordination is complicated and responsible task at the same time, decisions about protection devices' settings should be left to the user. All other tasks, which make protection coordination easier and more reliable, should be left to the computer.

II. Development of Protection Devices

In recent years protective devices have changed dramatically. Not long ago, for each protection function a separate device was needed. Today, numerical protection devices offer a combination of numerous control and protective functions, following the philosophy "one outgoing, one protective device". In other words, all protective and control functions of an outgoing are assembled in a single device. This is possible due to numerous functions and their possible combinations that modern devices provide. Numerical relays are controlled by microprocessors. The microprocessors technology has progressed and capabilities of such devices have been improved. This progress is reflected in the computing performance of protective devices. In 1985 prominent producers device (such as e.g. 7SJ50) had 256 bytes (not kb !) of ram and 32 kb of EPROM at 0.1 mips , in 2000 7SA6 (same producer) had 512 kb (4Mb optional) of ram and 4 Mb of EPROM at 35 mips. Besides far more memory, computing performance has increased by a factor 350. This improvement is in correspondence with the Moor's law that is valid for more or less 20 years. This also means that these devices can offer not only some standard protective functions, e.g. overcurrent, voltage protection, but also a variety of additional functions such as fault recording, performance supervision, etc. All this is integrated into a single device. With raising complexity the users may encounter difficulties. Naturally, users need to understand what they have got from a manufacturer in order to implement it efficiently. This is possible by studying an approximately 3 cm thick handbook. To wade through such texts and understand all of a device's possibilities can take a lot of time and patience. Computer-aided presentations of protection devices' characteristics can therefore play an important role in understanding protective-relay operation and their response to system disturbance. Without computer programs it is practically impossible to coordinate protection devices in a larger parts of an EPS, especially if overload or time-dependent overcurrent characteristics are applied.

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III. ADVANTAGES AND POSSIBILITIES OF COMPUTER-AIDED PROTECTION COORDINATION

The most important advantages of computer-aided protection coordination are:

- a unified platform for all tasks to be done in order to carry out the entire protection coordination,
- visualization of all existing protection devices' curves included in a database.
- a clear presentation of the device settings,
- a reliable final solution,
- a reduction in the time used for protection planning.

A modem power engineering software should fulfil basic requirements like:

- User-friendly graphical editor: a simple CAD system for drawing EPS schemes.
- Easy editing of device settings and the possibility to present those settings in EPS schemes.
- Preparation of EPS schemes and schemes of the protection device's settings for documentation.

Additionally, software for planning power system protection coordination should have the following qualities:

- A database of the existing protection devices' curves with setting area and possible grading.
- Application of user-defined protection devices (virtual devices with user-defined curves)
- A simple preview of the protection curves for all the protection devices and fuses in the database.
- Editable grading diagrams for all the devices included in a selected part of the EPS.
- Treatment of the whole EPS with many grading paths and curve charts in a single project.
- Network calculations needed coordination, e.g. minimum and maximum fault-current calculations for various network configurations in accordance with standards.
- Network representation in impedance (X or Z) scale for distance-protection settings purposes.

IV. THE CONCEPT OF A TOOL FOR POWER SYSTEM PROTECTION COORDINATION

In our concept we have developed a stand-alone tool. The main aim was to make a tool that was as simple and user-friendly for the user as possible. Any protection-planning engineer should be able to work with this tool after a short introduction. In our opinion the applicability of a program tool is questionable if a few hundred pages of user manual have to be studied before any work can start, especially if such a tool is not used frequently and the user exploits only some of the possibilities of the program. However, over time the tool became more complex with hundreds of possibilities available. Nevertheless, the goal of the development remained as simplicity and ease of use.

It should be stressed that the tool presented should only assist protection-planning engineer at specific procedures concerning O/C (over-current) coordination and is not meant to automate those procedures. Intentionally the tool is not "too smart", although the idea of automatically created protection coordination was attractive. With the years of experiences regarding O/C coordination we realized that the requirements of the operators and the specific circumstances in the power systems (mostly industrial power systems) were essentially different for almost each project. So "standard" setting is just not possible. Besides O/C protection-planning engineers want to deeply understand the problem of each specific project and this is enabled only if they are actively involved in each phase of work which has to be done. They simply do not rely on "computer logic" only, because protection planning is not just technical task but also a philosophy, as experienced engineers used to say. Namely the whole protection system (not only O/C protection) has to follow the specific "philosophy" in order to be coordinated.

Last but not least the O/C protection coordination is very responsible task. If something goes wrong the consequences may be catastrophical – i.e. disconnection of 1000 MW power plant or a large factory supply (in such a case cost may run into millions of EUR).

A. Communication with the user

In the proposed concept the graphical editor represents the main working environment. It is, first of all, intended for drawing the EPS schemes, although by applying basic graphical elements arbitrary schemes can also be drawn. The basic elements of electrical schemes are predefined and are treated as objects with certain properties. These properties may be graphical (element picture, its position in the scheme, line width and type, colour, text properties, affiliation to group, zoom factor etc.) or electrical (e.g. for protection: type, name, parameters, voltage level, CT ratio, etc.). Some of the predefined graphical elements are presented in fig. 1.

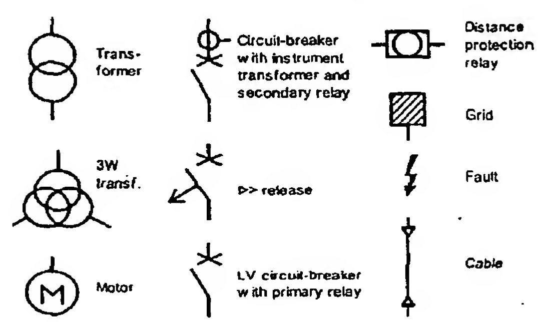

Fig. 1: Some of the predefined graphical elements

The main requirement that the graphical editor should fulfill is simplicity of use. A user should, in a few minutes be able to operate the program without having to read any manuals. In order to make the construction of the schemes easy, tools like gravity, snap, resize to snap etc. have been used. The elements are treated as vector graphics; graphical objects or a group of them can therefore be exported in WMF format (or copied into a clipboard) and later pasted into the same program environment, into word processors (e.g. MS

Word) or into graphics programs. The properties of the objects (e.g. line and/or pattern colour and/or style; numerical moving; resizing and rotating; deleting; copying; grouping; ungrouping of elements; etc.) can easily be modified by opening appropriate menus. The working panel is defined as an infinite area, which can be visually separated to pages. The main working window is presented in fig. 2.

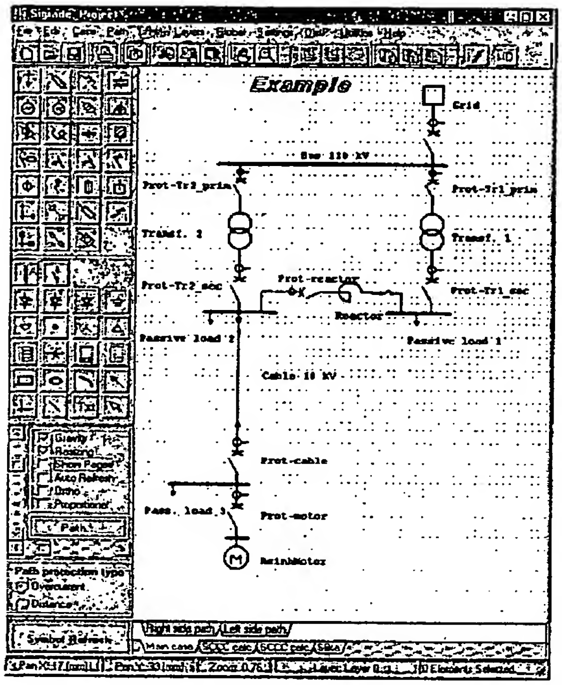

Fig. 2: The main working window

B. *Electrical Parameter Assignment*

EPS scheme should represents a situation in reality. This means that the elements must have certain electrical properties; those properties might be used for preparing documentation, calculating fault currents (e.g. a motor's rated power) or they might be relevant for protection coordination (e.g. relay settings). In the proposed concept the electrical data can be assigned to an element via a dialogue editor, or they can be copied among elements of the same type. The electrical-data dialogue editor for a transformer is shown in fig. 3.

One of the major advantages of this software is a large database, built in collaboration with Siemens, AG. This database include almost all protection devices ever used in their projects. It includes more than 650 protection devices and 750 fuses. Protection-element electrical data are connected to this database and as it is expected from a modern software, it is possible to create user-defined protection devices.

C. *Data management*

One of the most important facilities of many computer programs is data management. In protection coordination a huge number of existing protection devices and fuses are available. By deciding which protection device should be used at a specific point of the EPS, a fast preview and a comparison between the different curves of protection devices are necessary for fast and effective coordination. As protection devices are stored in a database, the visualization of protection device properties is simple. An example of comparison of some curves is presented in fig. 4.

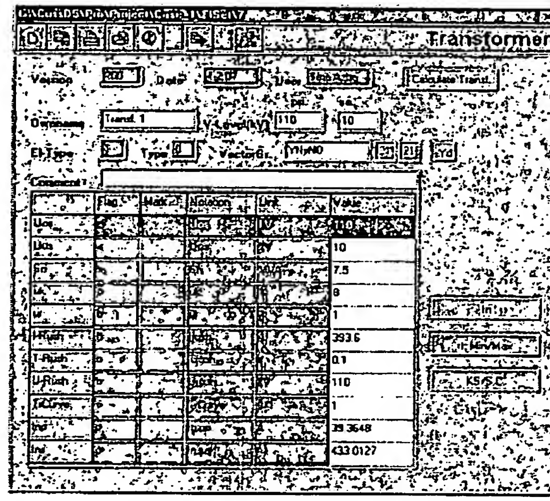

Fig. 3: Electrical parameter editor for a transformer

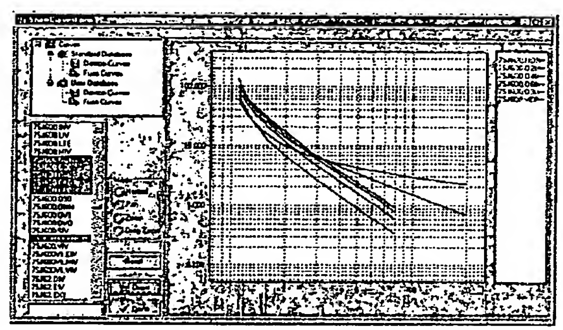

Fig. 4: The editor for fast preview of protection curves

A few other functions for data management greatly increase the practicality of a computer program. One of these functions is a list of all the elements with corresponding basic electrical data. Another function is a device report, where particular protection devices are listed in a table, together with the settings of the parameters. A table can be exported in MS Excel and further applied for a presentation of the device's settings.

D. Short-circuit current calculation (SCCC)

An additional function that is necessary for protection coordination is the calculation of short-circuit currents at particular points of the EPS. Different programs for SCCC exists on the market, but following the idea of using just one program for entire protection coordination, the function of SCCC was added to the concept of this software.

The minimum and maximum inter-phase faults as well as earth-fault currents must be calculated for each voltage level.

The fault position is defined simply by placing the pointer symbol at a specific position in the scheme of the EPS. Every such symbol contains data about fault parameters as well as the properties for a report of the SCCC results.

The results can be presented as a table of elements of the ESP with corresponding values of short-circuit currents and voltages. The second option for clear presentation of SCCC results is writing the corresponding values directly by the side of each element in the EPS scheme. Both options are presented in fig. 5.

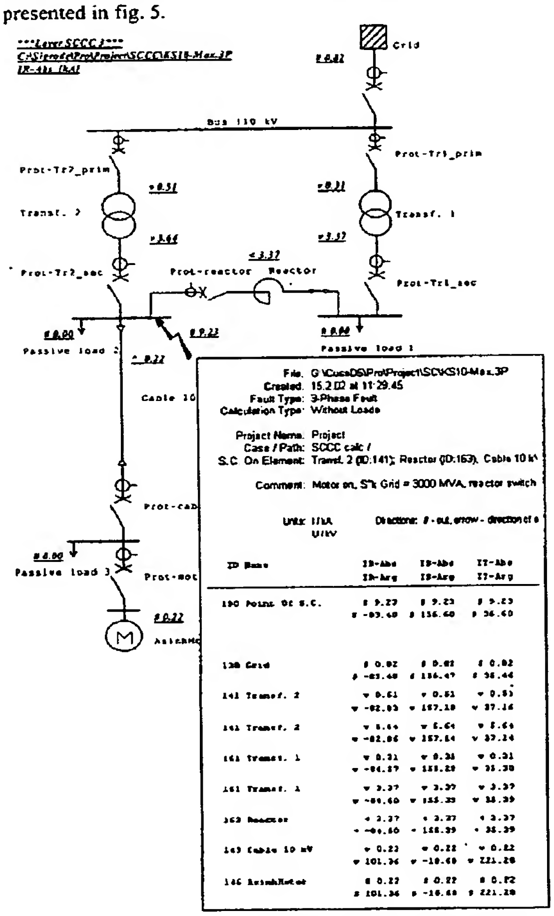

Fig. 5: Presentation of SCCC results as a table and in the EPS scheme

E. Planning of distance protection

Distance protection provides the basis for network protection in transmission systems and meshed distribution systems. For the purpose of planning distance protection a part of the EPS should be presented as a scheme of arranged lines in a X (or Z) / t diagram, where each line represents the impedance between two distance-protection devices in the EPS. The main effort in this field focuses on the fully automatic creation of a chosen EPS part in the X (or Z) / t diagram. A section of an automatically created distance-protection scheme is presented in fig. 6. Tripping schedules are created automatically according to the data entered for a particular protection device. In thick-meshed networks this construction may be quite time consuming work without such a tool. In addition, fully automated editing of such a scheme is provided.

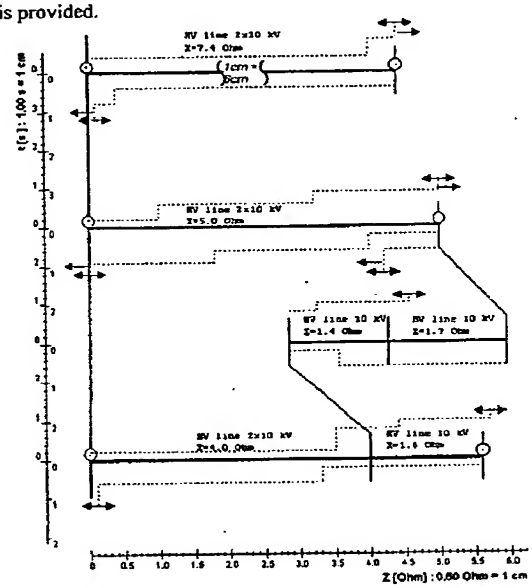

Fig. 6: Distance-protection scheme

F. Presentation of protection setting results

The results of the overcurrent protection grading procedure are the grading paths and the corresponding grading diagrams. Grading path is radial plot of elements, selected and defined as a path, with their electrical data, as presented on the left side of fig. 7. The setting range and the actual settings are provided by the side of each protection device. The grading diagrams are presented as double logarithmic time/current diagrams, as presented on the right side of fig. 7. Each characteristic corresponds to a certain voltage level; therefore, plotting of multiple current axes corresponding to chosen voltages should be possible. Besides *I/t* characteristics of the path elements, it is also possible to add points, current-level lines and/or fault-level areas to the grading diagram manually.

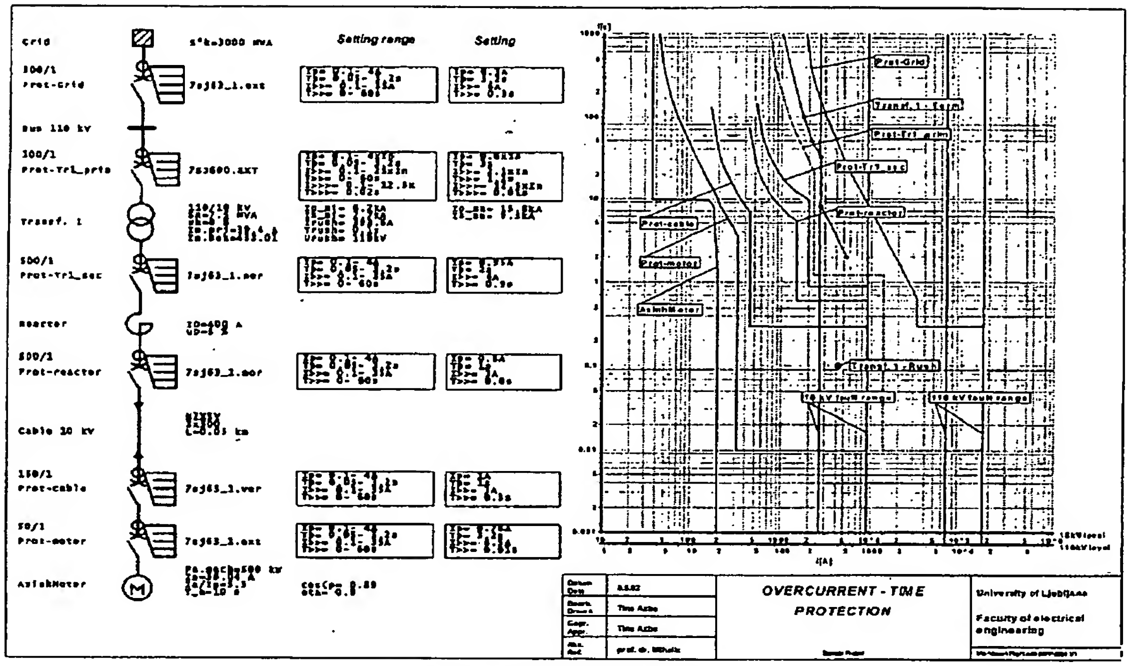

Fig. 7: Grading path and grading diagram

Editing of practically all the diagram properties (from line colour and style, to panel colour gradient or background bitmap, or even 3D view) is enabled. Simple and efficient editing of graphical properties is additionally enabled by using an existing or user-defined templates. An example of grading path with grading diagram is presented in fig. 7.

V. CONCLUSIONS

The Sigrade program is a software which helps a project-planning engineer to determine the setting parameters of overcurrent, overload and distance-protection devices in electrical power systems. The program concept meets the following requirements:

- easy to use,
- enables preparing of the entire documentation, including network schemes, tables, diagrams etc.,
- offers flexibility regarding data management,
- can also be used for presentation purposes,
- enables the inclusion of user-defined protection curves of standard types,
- calculates short-circuit currents.

The program philosophy is strongly oriented to specific procedure of over-current protection coordination

Future work will concentrate on checking of relay tripping in chosen fault cases and on the development of the "auto-setting" routines.

VI. ACKNOWLEDGMENT

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